4. Results and Accomplishments (Year 1 – until 12/31/2005)

The activities during this year of the project were primarily focused in two areas: (1) preliminary simulations with RAMS in preparation for the model experiments designed for this project, and (2) analyses of precipitation observations for the purpose of constructing a regional hydroclimatology and assess the utility and reliability of observational precipitation data.

4.1 Preliminary Simulations with RAMS

Simulations have been run with Version 4.4 of RAMS (hereafter referred to as RAMS-4.4) set up with a nested grid similar to the grid configuration proposed for this project. RAMS-4.4 simulated wind and domain-averaged precipitation fields have been found to agree reasonably well with the NCEP Regional Reanalysis and the NCEP Environmental Modeling Center's 4-km gridded, multi-sensor precipitation product, respectively. Simulations are currently being run at coarse resolution using the newest version of RAMS (Version 6.0), which includes an improved coordinate system designed specifically to simulate complex terrain and which has been shown to be superior at representing horizontal gradients of atmospheric fields near the land-surface over topographically complex regions. Among the first sensitivity tests will be a comparison of simulations generated using the old and new RAMS coordinate systems for two winter storms along the west coast United States.

4.2 Analyses of Observations

One of the primary goals of this research project is to assess whether the current class of state-of-the-art regional climate models is capable of accurately simulating the hydrometeorology of the western U.S. when configured with a very high resolution grid. This requires validation of RAMS simulated fields against the best available set of observations. However, obtaining accurate precipitation measurements over complex topography at the high resolution required for model validation is a challenge.

Table I. List of precipitation datasets available for the western United States

Dataset	*Spatial Domain*	*Temporal Domain*	*Temporal Resolution*	*Spatial Resolution*	*Sensor/Product Description*
CMAP[a]	*Global*	*1979-present*	*Monthly*	$2.5^o \times 2.5^o$	*Merged Product*
GPCPv2[b]	*Global*	*1979-present*	*Monthly*	$2.5^o \times 2.5^o$	*Merged Product*
GPCP 1DD[c]	*Global*	*1996-present*	*Daily*	$1^o \times 1^o$	*Merged Product*
NCEP2d[c]	*Global*	*1979-present*	*6-hr*	$2.5^o x 2.5^o$	*Numerical Model*
NARR[e]	*Regional*	*1979-present*	*3-hr*	*32 km*	*Numerical Model*
US-MEX[f]	*Regional*	*1948-present*	*Daily*	$1.0^o \times 1.0^o$	*Rain Gauge*
UDel[g]	*Regional*	*1950-1999*	*Monthly*	$1.0^o \times 1.0^o$	*Rain Gauge*
UWA[h]	*Regional*	*1949-present*	*Daily*	$1/8^o \times 1/8^o$	*Rain Gauge*

[a]*CPC Merged Analysis of Precipitation (Xie and Arkin, 1997);*
[b] *Global Precipitation Climatology Project Version 2 (Adler et al, 2003, Huffman et al, 1997)*
[c] *Global Precipitation Climatology Project 1 Degree Daily (Huffman et al, 2001)*
[d] *NCEP Global Reanalysis*
[e] *NCEP North American Regional Reanalysis (Messinger et al., 2003)*
[f] *Climate Prediction Center (CPC) United States and Mexican Daily Precipitation Analysis*
[g] *University of Delaware (Willmott et al., 1994)*
[h] *Daily gridded meteorological data obtained from the Surface Modeling Group at the University of Washington (Maurer et al.,2002);*

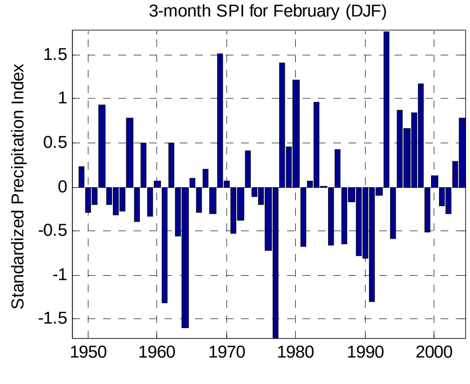
Several sources of precipitation data are currently available to provide information about the hydrometeorology of the western U.S., including measurements from rain gauge networks, ground-based radar, and earth-orbiting satellites. In general, rain gauge data are held to be the most accurate where they are available, but such measurements are sparse or void in regions of complex terrain such as the mountainous regions in the west. Ground Doppler radar estimates are available at a relatively high spatial/temporal scale over much of the U.S. and are able to provide quality precipitation estimates in many regions, but they are impeded or complicated by the presence of topography. Satellite precipitation estimates offer the advantage of increased spatial coverage, including over complex terrain. However, they contain a high level of uncertainty that varies over space and time and under different weather regimes, making the error and uncertainty difficult to quantify. Additionally, for latitudes poleward of 40º, geostationary satellite observations are not available and satellite precipitation estimates are therefore based on measurements from polar-orbiting satellites, which typically sample at a rate of 1-2 observations per day for a given location.

In order to extract meaningful information about climatology or weather, or to validate numerical model simulations using rainfall data, it is important to understand the strengths and weaknesses of each available data product for the particular area of interest, including a quantitative assessment of random error and bias. As part of this research project, a comparative investigation of the different sources of precipitation data available for the western U.S. is being conducted for the purpose of developing an observationally-based regional climatology. The goal is to (1) identify the scales of precipitation variability in the west and determine if their relative influence varies by sub-region or evolves over time and under differing synoptic-scale conditions such as El Niño, (2) determine which types of observational data are appropriate for studying the different scales of variability and (3) determine if the degree of uncertainty in precipitation observations is space and/or time dependent. The results of this analysis will be used to identify the dataset or collection of datasets most appropriate for use in validating the Regional Atmospheric Modeling System's ability to accurately represent the hydrometeorology of the western U.S.

We are currently working with several precipitation products available for the western U.S. including those developed from rain gauge networks, ground-based radar, geostationary satellite IR sensors, polar orbiting satellite microwave radiometers, and polar orbiting satellite radar measurements. The data along with their corresponding spatial and temporal domains and resolutions are given in Table 1 along with relevant references.

4.2.1 Long-term Hydroclimatology and Persistence

We have been evaluating the precipitation climatology of the western U.S. from 1948-2004 using the Standardized Precipitation Index (SPI) and observations. The SPI is a probability index (Edwards and McKee, 1997) that considers only precipitation, and which can be calculated over a range of temporal scales. In short, the SPI is an index based on the probability of recording a given amount of precipitation at a certain location. For each location and for each month, all observations in the record are fit to a gamma distribution, the probabilities are calculated and then normalized such that a value of zero indicates the median precipitation amount and the endpoints of -3 and +3 indicate extremely dry and extremely wet conditions, respectively (the SPI scale is shown in Figure 1, center). The SPI can be computed for several time scales, allowing various scales of variability to be studied. For example the 3-month SPI



SPI value	Description
2.0 and above	extremely wet
1.50 to 1.99	very wet
1.0 to 1.49	moderately wet
-0.99 to 0.99	near normal
-1.0 to -1.49	moderately dry
-1.50 to -1.99	very dry
-2.0 and below	extremely dry

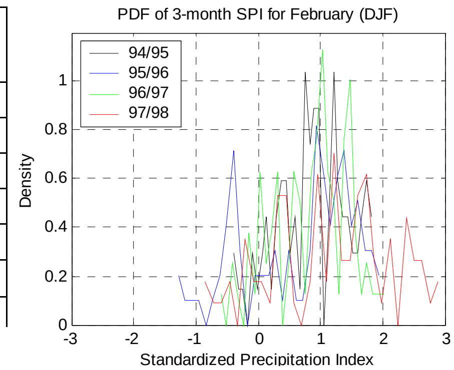


Figure 1. Time series of the 3-month SPI for February averaged over California/Nevada (left). The Standardized Precipitation Index scale and description (center). Probability distribution of the 3-month SPI for February for grid cells over California/Nevada during the four wet winters between 1994/1995 and 1997/1998. The precipitation data used to compute the SPI are from the Climate Prediction Center's United States and Mexican Daily Precipitation Analysis.

for February compares each three month (DJF) period to every other (DJF) period in the precipitation record and assigns to it a probability. Similarly, the 48-month SPI compares each two-year period to every other two-year period. As such, the SPI is able to capture the various scales of both short-term and long-term drought and wet periods. Figure 1 (left) shows the time series of the 3-month SPI for February averaged over California and eastern Nevada. Notable from the figure are the four consecutive wet winters beginning in the 1994/1995 season and lasting through the 1997/1998 season. This wet season persistence is not observed at any other time in the 1948-2004 record. The probability distribution of the 3-month SPI is given in Figure 1 (right), which illustrates the high occurrence of grid cells observing precipitation in the moderately wet (SPI of 1.0 to 1.49) to extremely wet (SPI of 2.0 and above) range during the 1994/1995 through 1997/1998 winter seasons.

Figure 2 gives the time series of the 48-month SPI averaged over California and eastern Nevada, which shows alternating occurrences of long-duration wet and dry periods of varying degrees and length. Notable are the long-lasting drought of the 1950/1960's and the two decade-long wet periods of the early 1980's and late 1990's. Figure 3 shows the wavelet power spectrum for normalized monthly mean precipitation for California and eastern Nevada (top), and the corresponding time series (bottom). Interestingly, the long term wet periods of the early 1980's

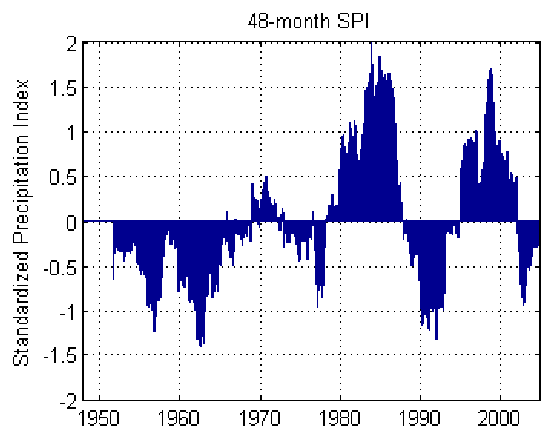


Figure 2. Time series of the 48-month SPI averaged over California/Nevada

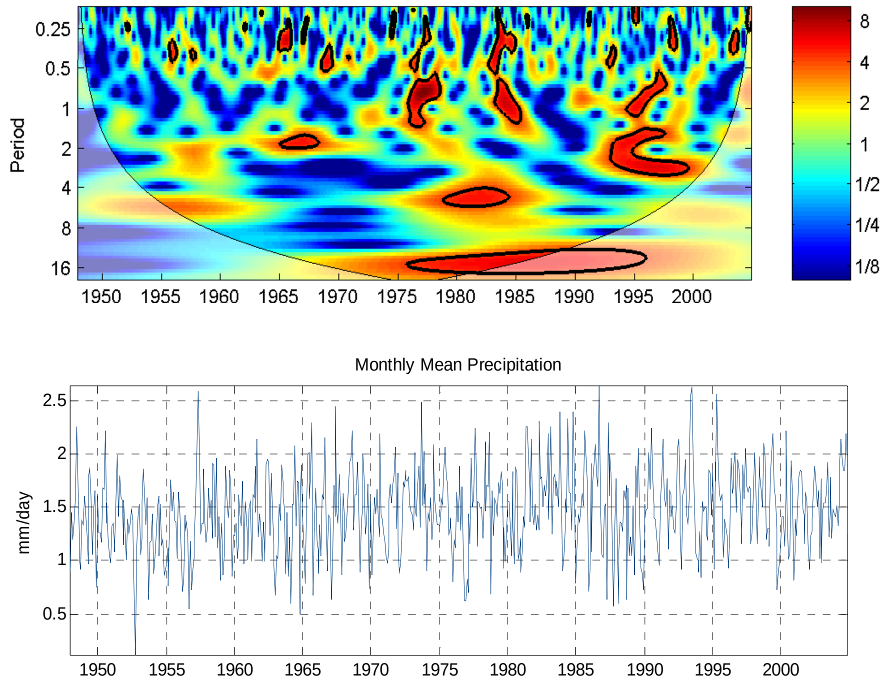


Figure 3. Wavelet power spectrum of normalized monthly mean precipitation for California and eastern Nevada (top). Monthly mean precipitation time series (bottom). The precipitation data are from the Climate Prediction Center's United States and Mexican Daily Precipitation Analysis (USMex).

and late 1990's that are observed in the 48-month SPI appear to occur when there are spectrum peaks in the 16-year band (the scale of the Arctic Oscillation) together with simultaneous peaks in higher-frequency (1-8 year) bands. We are currently exploring the use of the SPI as a tool with for use in climate signal detection at various scales for the western U.S.

4.2.2 A Comparison of Datasets for the West Coast United States

We are using the four consecutive wet winters as discussed above to compare several precipitation datasets. Ph.D. student Kristen Goris is currently preparing a paper entitled "A Comparison of Precipitation Datasets for the West Coast United States during Four Wet Winters". However, the paper may be expanded or a companion paper written to look at regions and seasons where the rainfall regime is more convective in nature. Differences in horizontal scale and grid-centers among the data required re-scaling for direct comparison. To date, all datasets have been regridded to a common 2.5-degree grid and those datasets with an original spatial resolution of 1-degree or higher have additionally been regridded to a common 1-degree grid. Figure 5 shows the average winter (DJF) precipitation rate for the 1994/1995 through 1997/1998 winter seasons for each dataset at its original spatial resolution. Figure 6 is the same as for Figure 5, but for the data regridded to a common 2.5-degree scale.

There is general agreement among the data that 97/98 saw a more enhanced southern progression of wet weather than was observed during the previous three winters. Additionally, the datasets all appear to observe 97/98 as the wettest winter for the northern part of California and all

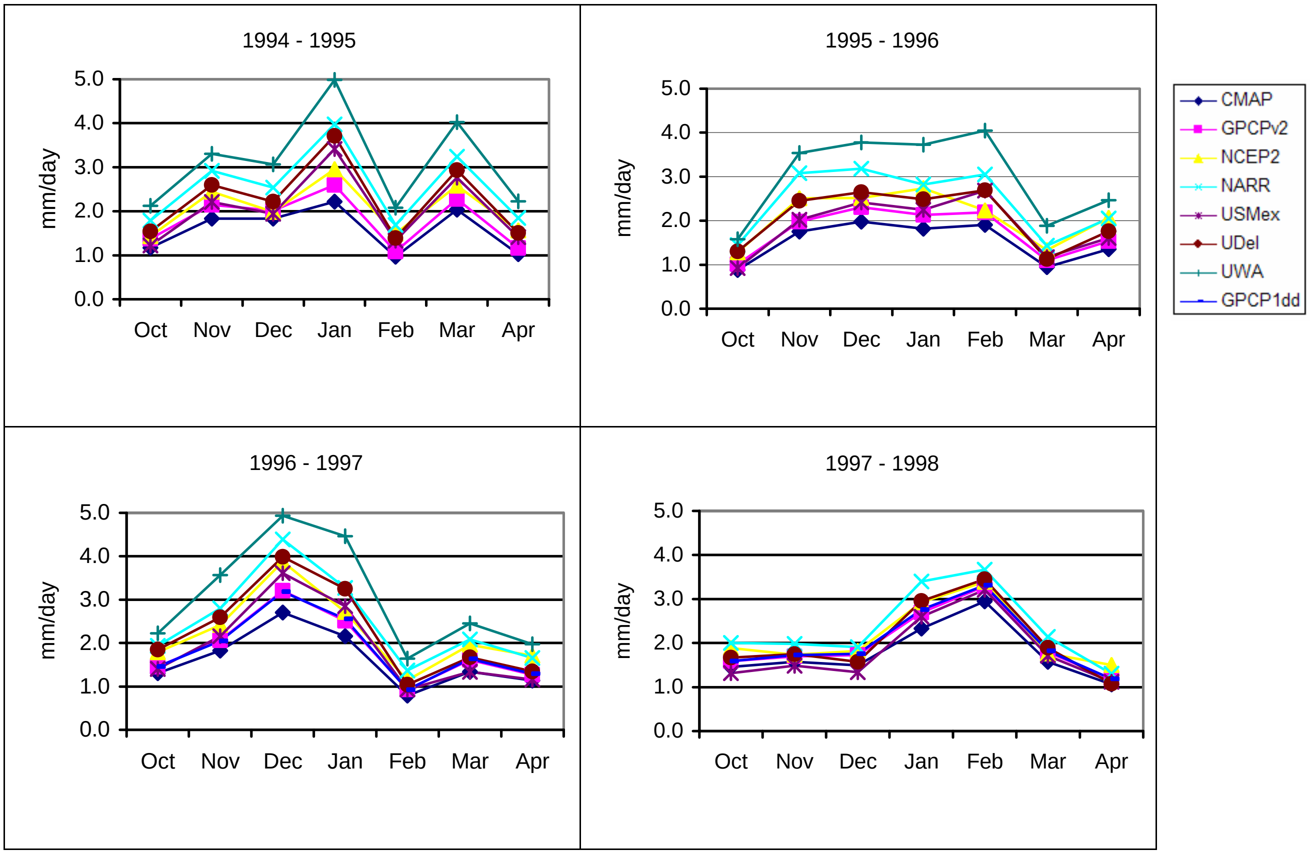
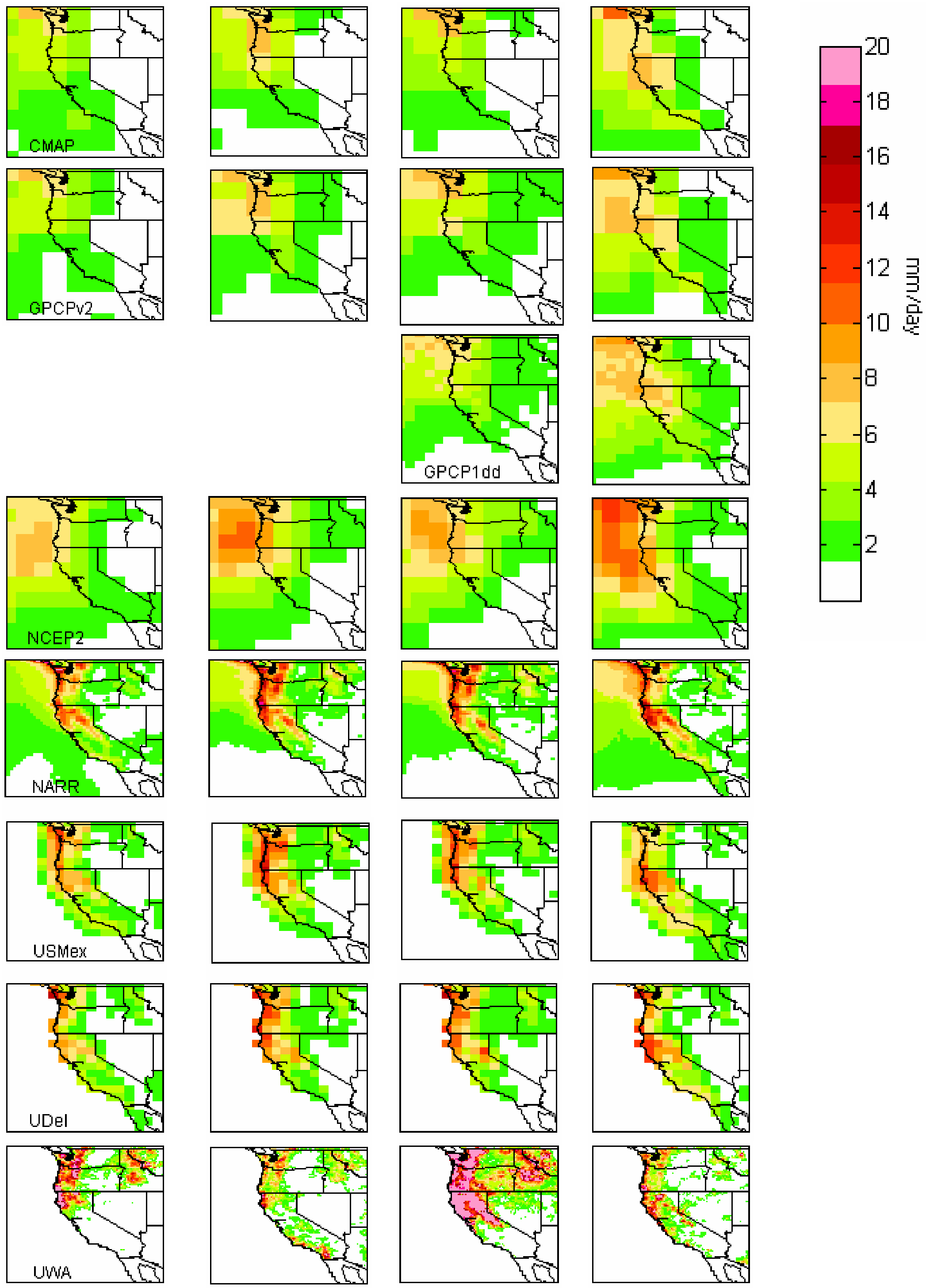
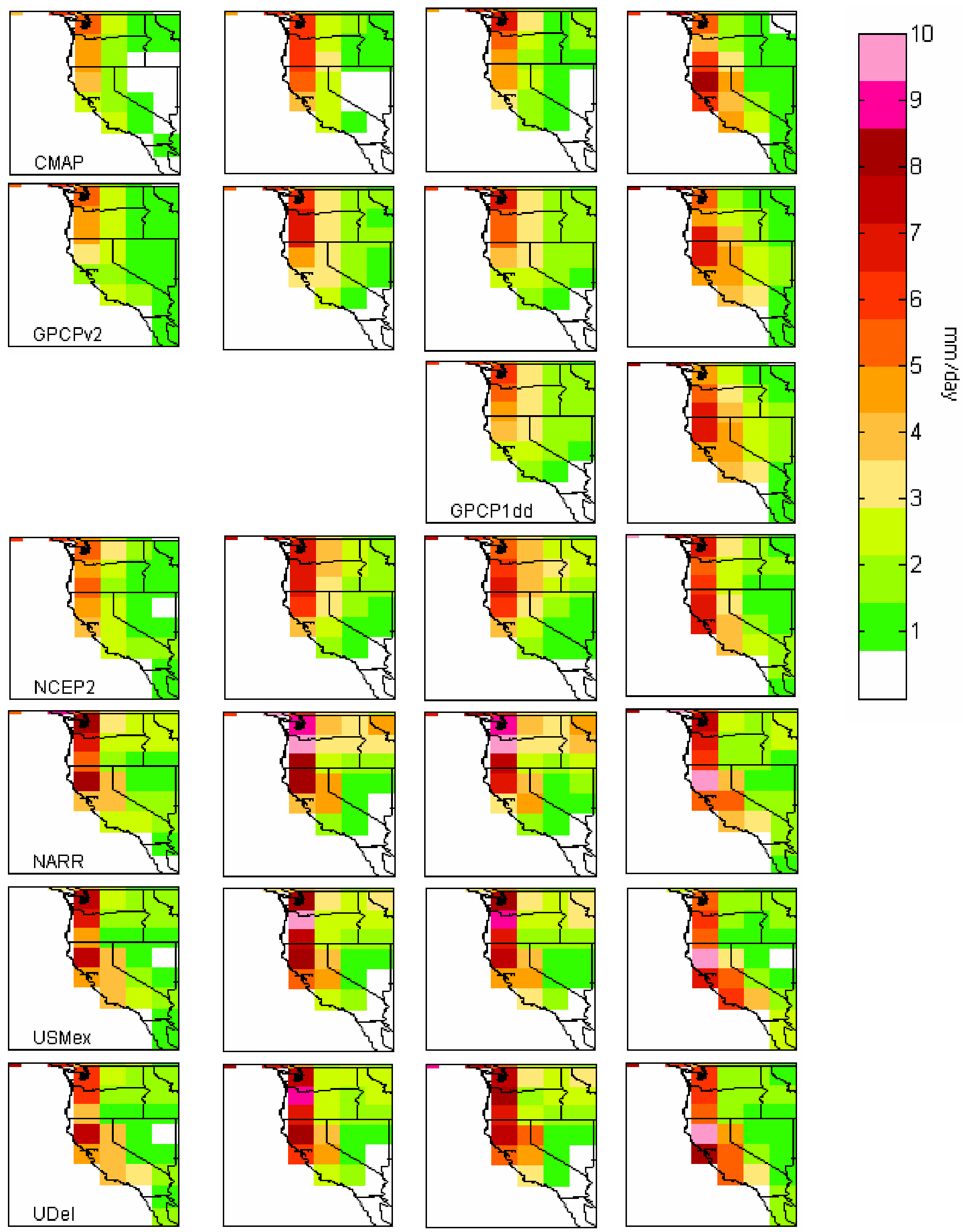


Figure 4. Domain averaged precipitation for the west coast United States for four consecutive wet winters

indicate that 95/96 and 96/97 were wetter for the Pacific Northwest. However, the interannual variability is much more pronounced for the data whose original spatial resolution is higher, even when comparing the data on the common 2.5-degree grid, as in figure 6. From Figure 6, the North American Regional Reanalysis (NARR), the Climate Prediction Center's United States and Mexican Daily Precipitation Analysis (USMex), and the University of Delaware raingauge product (UDel), which have a relatively high spatial resolution exhibit a much larger variation between winters than do the other datasets whose original spatial resolution is 2.5 x 2.5 degrees.

Figure 4 shows the results of domain averaged precipitation for the west coast United States. From the Figure there is general agreement between datasets with respect to intra-season trends such as monthly peaks and the temporal location of precipitation onset, but notable differences exist in precipitation magnitude and interannual variability. We are currently investigating whether these differences are an artifact of resolution alone or whether sampling error or weaknesses in remote-sensing precipitation algorithms may play a role. Daily data is being analyzed to distinguish the four winter seasons based on daily precipitation features such as precipitation frequency and intensity, which may help to explain why the between-dataset bias varies from year-to-year. For example, from Figure 4 there appears to be greater disagreement among data products during 94/95 and 95/96 than is observed during 97/98 and we are currently working to explain this variation in bias.


CMAP
GPCPv2
GPCP1dd
NCEP2
NARR
USMex
UDel
UWA
20
18
16
14
12
10
8
6
4
2
mm/day



CMAP
GPCPv2
GPCP1dd
NCEP2
NARR
USMex
UDel
10
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mm/day

5. Future Work (Year 2)

The second year of the project will focus on (1) completion of the observationally-based climatology and data comparison detailed above, which is expected to result in two or more publications during 2006, (2) validation of the RAMS model's ability to simulate precipitation in the Western Cordillera, which will generate a high resolution precipitation dataset that will likely have uses beyond the scope of this research project, and (3) conduct a series of sensitivity analyses designed to elucidate the roles of land surface parameters in modulating precipitation in the West. Publications are expected to result from the RAMS validation and sensitivity analyses, which will be submitted during 2006 and 2007.

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